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(54) **SPRING AND MANUFACTURING METHOD THEREOF**

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- **Expert opinion of Professor Dr Eckehard Muller dated 30.06.2016**
- **CV of Professor Dr Eckehard Muller**
- **Alleged public prior use by Mubea Motorkomponenten GmbH**
- **Production drawing No A 266 053 0120 of company Muhr and Bender KGE**
- **Drawing dated 9 February 2005, "Z Nr ? DC M266V36K" File V36K VFKE**
- **Laboratory report A-333/16_K dated 10.05.2016**
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- **Delivery note of Mubea Motorkomponenten GmbH dated 17 December 2007**
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EP 2 682 493 B2

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Description

Technical Field

5 **[0001]** The present invention relates to a production method for a spring.

Background Art

10 **[0002]** For example, materials for valve springs for automobile engines may include oil tempered carbon steel wires (SWO-V), oil tempered chromium-vanadium steel wires (SWOCV-V), and oil tempered chromium-silicon steel wires (SWOSC-V), which are specified in the Japanese Industrial Standards (JIS). The oil tempered chromium-silicon steel wires are conventionally widely used in view of the fatigue resistance and the sag resistance. In recent years, reduction in weight of the valve spring is strongly desired in order to improve fuel efficiency of automobiles, and there is a trend of increasing tensile strength in spring wire so as to increase design stress of the valve spring. In a case of a spring wire such as an oil tempered wire specified in the JIS, notch sensitivity to cracks and defects such as inclusions is greatly increased according to the increase in the strength of the spring wire. Therefore, such a spring wire is more likely to break during cold spring forming (coiling) and for brittle fracture to occur while in use. In a coil spring after it is coiled, tensile residual stress is generated in a direction in which external compressive force is applied during the coiling, and compressive residual stress is generated in a direction in which external tensile stress is applied during the coiling. Therefore, a spring wire with higher tensile strength tends to have these residual stresses at greater values. In addition, when a coil spring is compressively deformed, highest tensile stress is applied on a surface at an inner diameter side of the coil spring. Therefore, when a cold-formed coil spring is compressively deformed, high tensile stress is applied on the inner diameter side of the coil spring in addition to the tensile residual stress that is generated after it is coiled. Accordingly, the inner diameter side of the coil spring is likely to decrease of fatigue strength.

25 **[0003]** In order to correspond to this, high compressive residual stress may be provided on a surface layer of a spring wire from a surface to deep inside the spring wire. For example, shot peening is widely used for providing compressive residual stress on a surface layer of a spring wire in order to improve the fatigue resistance of a spring. By increasing the compressive residual stress at the surface layer by shot peening, breakage originating from the surface at an early time may be prevented. However, since the yield strength is increased according to increase in the hardness of a spring wire, the amount of plastic strain that can be provided on the surface layer by the shot peening is decreased, and a thick compressive residual stress layer becomes difficult to form. The thickness of the compressive residual stress layer is a distance from the surface to a position where the compressive residual stress is zero. On the other hand, according to the increase in design stress, combined stress of applied stress and residual stress (net stress applied to an inside of a spring wire) reaches a maximum at around a depth of 200 to 600 μm from the surface. This depth from the surface in a radial direction depends on the diameter of the spring wire, the degree of the applied stress, and the like. If inclusions with sizes of approximately 20 μm exist within this area, stress concentrates on the inclusions. The concentrated stress may exceed the fatigue strength of the spring wire and make the inclusions starting points of breakage. Accordingly, the following techniques were disclosed in order to solve these problems.

30 **[0004]** International Laid Open No. WO2005/081586 and Japanese Unexamined Patent Application Laid-open No. 2008-115468 disclose a method for induction heating a coiled member. However, these references are silent about characteristics such as material strength and metallic structure after induction heating, and effect of the induction heating is unknown.

45 **[0005]** A spring with superior fatigue resistance is disclosed in Japanese Unexamined Patent Application Laid-open No. 64-83644. This spring is produced by using an oil tempered wire rod in which an element such as V is added in the chemical composition of the steel that is specified in the JIS. The additional element increases toughness of the steel material by refining crystal grains and thereby improves the fatigue resistance; however, this increases the material cost.

50 **[0006]** A spring made of a silicon killed steel wire with superior fatigue characteristics is disclosed in Japanese Unexamined Patent Application Laid-open No. 2008-163423. The spring is obtained by coiling a steel material in which the amounts of Ba, Al, Si, Mg, and Ca are adjusted. In order to add these elements in balanced amounts, the process of steel refining is very difficult to control, whereby the production cost is high.

55 **[0007]** A spring with superior fatigue strength is disclosed in Japanese Unexamined Patent Application Laid-open No. 2005-120479. In this spring, the chemical composition of the steel is adjusted, and grain size is decreased while the size of inclusions is decreased because the inclusions may become starting points of fatigue failure. In this spring, the fatigue strength is increased, but the degree of the fatigue strength (maximum shear stress τ_{max} = approximately 1200 MPa) is lower than a practical strength (τ_{max} = approximately 1300 to 1400 MPa). The practical strength is required of lightweight and high strength valve springs of recent years. In addition, a method of further performing a nitriding treatment for obtaining higher fatigue strength is disclosed in Japanese Unexamined Patent Application Laid-open No. 2005-120479. The nitriding treatment can increase the surface hardness, whereby the fatigue resistance may be im-

proved. In this method, iron nitrides are formed on a surface layer and must be completely removed after the nitriding treatment, because the iron nitrides may cause decrease in the fatigue strength. Therefore, the production process is complicated, and the cost of the nitriding treatment is high, whereby the production cost is high.

5 [0008] A spring steel wire with superior cold formability and high fatigue strength is disclosed in Japanese Unexamined Patent Application Laid-open No. 2-57637. This spring steel wire is obtained by adding Mo, V, and the like, to a chemical composition of a spring steel that is specified in the JIS and by austempering treatment. In this technique, the yield ratio (ratio of yield strength to tensile strength) is set to be not more than 0.85 in order to decrease tensile residual stress that may remain at the inner diameter side of a coil spring after the spring steel wire is cold formed. However, even when a spring wire with a yield ratio of not more than 0.85 is cold coiled and is then annealed, it is difficult to sufficiently decrease the tensile residual stress, which is generated after the cold coiling, from the surface to the inside. Therefore, even by subsequently performing shot peening, it is difficult to provide compressive residual stress from the surface to the deep inside, whereby improvement in fatigue resistance is limited.

10 [0009] EP1619264A1 discloses a steel wire for high-strength spring having superior workability, fatigue properties and sag resistance.

15 Disclosure of the Invention

[0010] An object of the present invention is to provide a production method for a coiled spring with superior fatigue resistance. The spring is produced by decreasing the material cost in a simplified process.

20 [0011] The inventors of the present invention conducted intensive research on fatigue strength of a valve spring with high strength. As a result, the inventors of the present invention had the following idea. That is, residual stress generated after coiling can be reduced by annealing as the treatment temperature is high. On the other hand, the material is softened through annealing and there is limitation for increase of anneal softening resistance. Therefore, it is naturally difficult to remove tensile residual stress while maintaining high strength of springs. Thus, the inventors of the present invention have found the following effective method. That is, a spring is heated to a high temperature of an austenitizing temperature after cold coiling, so that residual stress generated by the coiling is decreased to be substantially zero, after this, the structure is improved. The spring which is heated to an austenitizing temperature is rapidly cooled down to around room temperature, thereby obtaining a hard martensitic structure. Then, tempering with special conditions is performed, thereby obtaining a tempered martensitic structure which is well-balanced in strength and ductility. Then, shot peening is performed, thereby forming a high compressive residual stress layer which is formed from a surface to deep inside, thereby improving fatigue resistance.

25 [0012] Moreover, the inventors of the present invention found the following. That is, by performing strain aging in which a spring is heated with special conditions and performing setting in which permanent strain is provided to the spring, permanent set generated during practical use as a spring is reduced, whereby sag resistance is improved. A coil spring, in which high compressive residual stress layer is provided from a surface to deep inside, may be made of an inexpensive material such as an oil tempered wire that is specified in the JIS. In addition, the coil spring having superior fatigue resistance is produced by performing ordinary shot peening, strain aging, and setting in a later step without a special complicated heat treatment step as long as an appropriate heat history condition is selected so as to form a predetermined structure and predetermined concentrations of alloying elements are set. Moreover, the coil spring has high fatigue resistance corresponding to the requirements of the markets even when a nitriding treatment is not performed, whereas the nitriding treatment is usually performed. Accordingly, the processing cost is decreased, and the process is simplified.

30 [0013] The present invention as defined in claim 1 results in a coiled spring comprising: a composition consisting of, by mass %, 0.5 to 0.7 % of C, 1.0 to 2.0 % of Si, 0.1 to 1.0 % of Mn, 0.1 to 1.0 % of Cr, not more than 0.035 % of P, not more than 0.035 % of S, and the balance of Fe and inevitable impurities; a structure including not less than 95 % of tempered martensitic structure by area ratio in a cross section of a wire material; a compressive residual stress layer formed from a surface to a depth of 0.35 mm to D/4, in which D (mm) is a circle-equivalent diameter of a cross section, the compressive residual stress layer having maximum compressive residual stress of 800 to 2000 MPa; a center portion with Vickers hardness of 550 to 700 HV in the cross section; and a high hardness layer with greater hardness than the center portion by 50 to 500 HV from a surface to a depth of 0.05 to 0.3 mm, wherein the circle-equivalent diameter of the cross section of the wire material is 1.5 to 15 mm. The present invention can be applied to a stabilizer, a plate spring, a tension rod, and a disk spring.

35 [0014] The present invention provides a production method for a coiled spring, according to claim 1 the method comprising: a step of preparing an oil tempered wire consisting of, by mass %, 0.5 to 0.7 % of C, 1.0 to 2.0 % of Si, 0.1 to 1.0 % of Mn, 0.1 to 1.0 % of Cr, not more than 0.035 % of P, not more than 0.035 % of S, and the balance of Fe and inevitable impurities; and the following steps performed in order; a step of cold coiling the oil tempered wire into a shape of a spring; a hardening step for heating the spring up to an austenitizing temperature and cooling down the same to room temperature; tempering step for heating the spring and cooling the same to room temperature; a first shot peening step for projecting shots to the spring; a strain aging step for heating the spring and cooling the same; and a setting step

of providing permanent strain to the spring.

[0015] According to the present invention, a spring with superior fatigue resistance produced by the method of claim 1 is obtained without performing a complicated heat treatment and a surface hardening treatment by using a spring wire which is easily available. The spring wire does not contain expensive alloying elements and has a composition of a spring steel that is specified in the JIS. The spring has a high hardness layer and a thick high compressive residual stress layer on a surface layer. The spring has superior recycling efficiency because the amounts of the alloying elements are small. In addition, the production process is simple, and processing time is decreased, whereby productivity is improved and energy is saved.

[0016] Reasons for limiting chemical composition of a steel that is used in the present invention will be described. The symbol "%" represents "mass %" in the following descriptions.

C: 0.5 to 0.7 %

[0017] C is important for obtaining high strength of not less than 1800 MPa. In order to obtain the effect, it is necessary to add C at not less than 0.5 %. On the other hand, if the concentration of C is excessive, ductility is decreased. Therefore, the amount of C is set to be not more than 0.7 %. Thus, C is added at 0.5 to 0.7 %.

Si: 1.0 to 2.0 %

[0018] Si has a solid solution strengthening effect and is effective for obtaining high strength. In contrast, if the concentration of Si is excessive, workability of a raw material is greatly lowered and production is difficult. Accordingly, the concentration of Si is set to be not more than 2.0 %. Thus, Si is added at 1.0 to 2.0 %.

Mn: 0.1 to 1.0 %

[0019] Mn improves the quenchability of a steel material and added at not less than 0.1 % to obtain the ratio of tempered martensite of the present invention. On the other hand, if the concentration of Mn is excessive, segregation occurs, whereby workability is easily decreased. Therefore, the concentration of Mn is set to be not more than 1.0 %. Thus, Mn is added at 0.1 to 1.0 %. Cr: 0.1 to 1.0 %.

[0020] Cr improves the quenchability of a steel material and facilitates strengthening, and is added at not less than 0.1 %. On the other hand, if Cr is added at more than 1.0 %, iron carbides are easily generated, and the ductility lowered. Accordingly, the concentration of Cr is set to be not more than 1.0 %. Thus, Cr is added at 0.1 to 1.0 %.

P, S: not more than 0.035 %

[0021] P and S facilitate grain-boundary fracture by grain-boundary segregation. Therefore, the concentrations of P and S are desirably lower, and they are impurities, the upper limits of the concentrations of P and S are set to be 0.035 %. The concentrations of P and S are preferably not more than 0.01 %.

[0022] Next, the reason for limiting area ratio of structure will be described. Tempered Martensite: not less than 95 %

[0023] "Tempered martensite" is defined as a structure which is obtained by heating a material to an austenitizing temperature, rapidly cooling the material and obtaining a martensitic structure, then, heating (tempering) the material and decomposing the material into ferrite and iron carbides. Martensite contains C as austenitic C in a supersaturated solid solution, and has very high hardness and low ductility. Therefore, martensite is subjected to tempering and discharged suitable amount of C while precipitating iron carbides, thereby improving ductility. According to the present invention, a tempered martensitic structure having high strength and high ductility, and the area ratio is required to be not less than 95 % to obtain superior fatigue resistance. If the area ratio of the tempered martensitic structure is less than 95 %, soft residual austenite, ferrite, pearlite are largely contained, whereby the fatigue resistance is lowered.

[0024] Next, reasons for limiting various characteristics in a cross section of a spring wire will be described. It should be noted that "cross section" is a section perpendicular to the longitudinal direction of a wire material of a spring.

Compressive Residual Stress Layer

[0025] Compressive residual stress is provided on a surface layer primarily by shot peening. In the present invention, the thickness of the compressive residual stress layer on the surface layer from a surface is set to be 0.35 mm to D/4. The area from a surface to a depth of 200 μm to approximately D/4 tends to become a starting point of fatigue failure due to combined stress of residual stress and stress that is applied by an external load when a spring wire has a diameter in the present invention. Therefore, less than 0.35 mm of the thickness of the compressive residual stress layer is insufficient for preventing fatigue failure that originates from the inside. On the other hand, if the compressive residual

stress layer is too thick, tensile residual stress is greatly increased in order to balance stress in the entirety of the steel material. The tensile residual stress exists at an area that is deeper than a depth (crossing point) at which the compressive residual stress is zero. The tensile residual stress is combined with the tensile stress, which is generated in the spring wire by an external load, and facilitates generation of cracks. Therefore, the upper limit of the thickness of the compressive residual stress layer is set to be D/4.

[0026] The compressive residual stress layer is made so as to have maximum compressive residual stress of 800 to 2000 MPa. The maximum compressive residual stress is desirably higher in order to prevent generation and growth of fatigue cracks, and not less than 800 MPa of the maximum compressive residual stress is necessary in consideration of using the spring by setting high design stress. On the other hand, if the maximum compressive residual stress on the surface layer is too high, the tensile residual stress in the area that is deeper than the crossing point, which is generated for balancing the stress, may cause internal fracture, as described above. Accordingly, the upper limit of the maximum compressive residual stress is set to be 2000 MPa.

High Hardness Layer

[0027] In order to obtain necessary strength that is sufficient to withstand a load as a spring, not less than 550 HV of Vickers hardness is necessary at the center (center of gravity) of a cross section of a spring wire. On the other hand, if the hardness is too high, in general, the elongation is decreased, and notch (crack) sensitivity of the steel material is increased, whereby the fatigue strength may be decreased. Therefore, the hardness at the center of a cross section of a spring wire is set to be not more than 700 HV. A high hardness layer on the surface layer of the spring is effective for preventing generation of cracks and needs to have greater Vickers hardness than the center by not less than 50 HV. On the other hand, if the hardness of the high hardness layer is too high, the high hardness layer is embrittled. Therefore, the upper limit of the difference in the hardness between the high hardness layer and the center is set to be not more than 500 HV. In addition, not less than 0.05 mm of the thickness of the high hardness layer is necessary in order to prevent generation of cracks. On the other hand, if the high hardness layer is too thick, the toughness of the steel material is decreased. Therefore, the thickness of the high hardness layer is set to be not more than 0.3 mm.

[0028] A production method for a spring of the present invention will be described.

Forming Step

[0029] The forming step is a step for cold coiling an oil tempered wire into a predetermined shape.

[0030] The forming may be performed by using a spring forming machine (coiling machine) or by using a cored bar.

Seating Surface Grinding Step

[0031] This step is performed as necessary. In this step, both end surfaces of the coiled steel material are ground so as to be flat surfaces that are perpendicular to an axis thereof.

Hardening Step

[0032] In the hardening step, the austenitizing temperature is set at a temperature of Ac3 point to (Ac3 point + 250 °C) and the cooling rate to room temperature is not less than 20°C/second. Austenitizing must be performed at a temperature of Ac3 point to (Ac3 point + 250 °C), and the residual stress generated in the coiling can be substantially zero. Therefore, the austenitizing temperature is very important controlling factor for a production method for realizing the spring in the present invention. If the austenitizing temperature is lower than Ac3 point, the material is not austenitized (tempered martensite is not obtained inevitably), and a predetermined structure is not obtained. On the other hand, if the austenitizing temperature exceeds (Ac3 point + 250 °C), diameters of prior austenite grains tend to be increased, whereby the ductility may be decreased. Coarse prior austenite grains may cause decrease of fatigue resistance. Therefore, average diameter of the prior austenite grains after hardening step is preferably 20 μm or less.

[0033] The rate of cooling down the coiled steel material to room temperature after the austenitizing is desirably higher to stably obtain martensite, and the cooling needs to be performed at a cooling rate of not less than 20 °C/second, preferably, not less than 50 °C/second. If the cooling rate is less than 20 °C/second, ferrite and pearlite are largely generated during the cooling, and the structure that is described in the present invention is not obtained.

Tempering Step

[0034] Since a martensitic structure obtained by the hardening step is greatly low in ductility and toughness, the material is reheated and cooled down to room temperature to obtain well-balanced in strength, ductility and toughness.

In the tempering step, the material is heated at a temperature of 330 to 480 °C for 20 minutes or more. This is a very important controlling factor for a production method for realizing the spring in the present invention. If the heating temperature is less than 330 °C, decomposing of martensite into ferrite and iron carbides is not sufficient, and toughness of the martensite is hardly improved. On the other hand, if the heating temperature is more than 480 °C, the iron carbides are promoted to be coarse, whereby strength for bearing required load as a spring cannot be obtained. If the heating time is less than 20 minutes, the decomposing of martensite is not sufficient, whereby ductility and toughness are not sufficient. It should be noted that even if the heating time is more than 60 minutes, the balance of strength, ductility and toughness hardly changes. Therefore, the heating time is preferably 60 minutes or less with consideration of production efficiency and production cost.

First Shot Peening Step

[0035] The first shot peening is a method of providing compressive residual stress on a surface of a spring material by colliding a shot of metal or sand on the spring, whereby the fatigue resistance of the spring are greatly improved. In the present invention, the residual stress generated in the forming step reduced to substantially zero by the hardening step, and compressive residual stress can be provided on a surface layer of a spring wire from a surface to deep inside the spring wire. Therefore, the shot peening step is important step to obtain required compressive residual stress.

[0036] In the first shot peening step, the shots has a sphere-equivalent diameter of 0.6 to 1.2 mm, and the shots are projected at a speed of 60 to 100 m/second to cause coverage of 100 % or more. If the sphere-equivalent diameter of the shots is less than 0.6 mm, since the projecting energy is small, required compressive residual stress cannot be obtained. On the other hand, if the sphere-equivalent diameter of the shots is more than 1.2 mm, since the projecting energy is too large, the surface roughness of a surface of a spring is disadvantageously large and cracks easily formed on a surface of a spring. If the projecting speed is out the range of 60 to 100 m/second, it is disadvantageous in view of the sphere-equivalent diameter of the shots. If the coverage is less than 100 %, tensile stress is remained at a portion to which the shots did not collide, and the portion causes decrease of fatigue resistance of the spring.

[0037] It should be noted that the shot peening can be repeated several times. In this case, the sphere-equivalent diameter of the shots used in the prior shot peening is preferably larger than that of the shots used in the later shot peening. By such a manner, the surface roughness which was increased by the prior shot peening can be reduced by the later shot peening.

[0038] The shot peening may be performed by using a shot of cut wires, steel balls, high hardness particles such as of the FeCrB type, or the like. The degree of the compressive residual stress can be adjusted by a sphere-equivalent diameter of the shot, shooting speed, shooting time, and a multistep shooting process.

Strain Aging Step

[0039] Strain provided in a wire material in the shot peening step includes a large amount of dislocation. It is known that permanent set is caused by movement of the dislocation. Permanent set of a spring causes some disadvantages such that the spring cannot bear predetermined load. Therefore, in order to inhibit movement of dislocation, a spring is heated (strain aging). It is known that solid solution atoms such as C move around a dislocation by strain aging, whereby the dislocation is fixed and amount of permanent set is decreased.

[0040] In the strain aging step of the present invention, a spring is heated at a temperature of 150 to 300 °C for 10 minutes or more. If the heating temperature is less than 150 °C, movement of C is not sufficient and the dislocation is not sufficiently fixed, and amount of permanent set is large. If the heating temperature is more than 300 °C, the compressive residual stress obtained by the shot peening is decreased, and fatigue resistance is decreased. If the heating time is less than 10 minutes, movement of C is not sufficient and the dislocation is not sufficiently fixed, and amount of permanent set is large. Even if the heating time is more than 60 minutes, effect of fixing dislocation is saturated. Therefore, the heating time is preferably 60 minutes for production efficiency and cost.

Setting Step

[0041] The setting step is performed by providing plastic strain to a material so as to improve the elastic limit and to decrease the amount of amount of permanent set (sag). In the setting step, the spring is heated at a temperature of 150 to 300 °C and share strain of 0.015 to 0.022 is generated on a surface of the wire material. The setting step is performed for obtaining the same effect of the strain aging step. The setting is performed at the same temperature (150 to 300 °C) as in the strain aging, whereby sag resistance is further improved. If the share strain generated on a surface of the wire material is less than 0.015 in the setting, plastic strain is small, and permanent set is large. If the share strain is more than 0.022, a pre-crack is formed on a surface of the wire material, the crack extends while the spring is used, the spring may be broken within shortened service life.

Second Shot Peening Step

[0042] It is preferable to perform a second shot peening step for projecting shots again after the setting step. The shots in the second shot peening step has a sphere-equivalent diameter which is smaller than that of the shots used in the first shot peening step. This step is optionally performed. Since the shots having smaller sphere-equivalent diameter than that in the in the first shot peening is used in the second shot peening step, the compressive residual stress on a surface of a wire spring material is increased and the surface roughness is reduced, whereby the fatigue resistance is improved. Since the strain provided in the wire material is restricted within a greatly thin layer in a surface, amount of permanent set in the production process is very small and substantially rise no problem.

[0043] According to the present invention, material cost can be reduced and production process can be simple, and a spring having superior fatigue resistance can be obtained.

Brief Description of Drawings

[0044] Fig. 1 shows an example of a production process of a spring according to the present invention.

Best Mode for Carrying Out the Invention

[0045] The present invention will be explained in detail. Fig. 1 shows an example of a production process of a spring according to the present invention. An oil tempered wire consisting of, by mass %, 0.5 to 0.7 % of C, 1.0 to 2.0 % of Si, 0.1 to 1.0 % of Mn, 0.1 to 1.0 % of Cr, not more than 0.035 % of P, not more than 0.035 % of S, and the balance of Fe and inevitable impurities is prepared. The wire is cold coiled into a predetermined shape using a coiling machine (coiling step), after austenitizing at a temperature of Ac3 point to (Ac3 point + 250 °C), the spring is cooled down to room temperature at a cooling rate of not less than 20 °C/second (hardening step). The residual stress generated in the coiling can be substantially zero by this step. Since the spring is rapidly cooled after austenitizing, a martensitic structure can be obtained while inhibiting generation of large amount of ferrite and pearlite.

[0046] Next, the spring is heated at a temperature of 330 to 480 °C for 20 minutes or more, and is cooled down to room temperature (tempering step). By this step, the martensite decomposes into ferrite and iron carbides, whereby a structure (tempered martensite) which is well-balanced in strength, ductility and toughness.

[0047] Then, shot peening (first shot peening) composed of a first step using a round cut wire and a second step using a round cut wire with smaller sphere-equivalent diameter than that in the first step is performed. In the first shot peening step, the shots has a sphere-equivalent diameter of 0.6 to 1.2 mm, and the shots are projected at a speed of 60 to 100 m/second so as to cause coverage of 100 % or more. In the hardening step, the residual stress generated in the coiling is removed to be substantially zero. In the shot peening step, high compressive residual stress is provided on a surface layer of a spring wire from a surface to deep inside the spring wire. Therefore, the fatigue resistance is greatly improved by the shot peening.

[0048] Next, the spring is heated at a temperature of 150 to 300 °C for 10 minutes or more, and is cooled (strain aging). In the shot peening step, strain is provided in a spring wire, the strain includes a large amount of dislocation. Therefore, in the strain aging step, the spring is heated and solid solution elements such as C are moved around the dislocation, thereby fixing the dislocation. Therefore, movement of the dislocation is inhibited.

[0049] Furthermore, the spring is heated at a temperature of 150 to 300 °C and permanent set is provided to the spring so that share strain of 0.015 to 0.022 is generated on a surface of the spring (setting step). In this step, the elastic limit is improved by providing plastic strain, and amount of permanent set is reduced. Furthermore, as a third step of shot peening, shot peening (second shot peening) using sand particles with a smaller sphere-equivalent diameter than that in the second step is performed.

[0050] The spring produced by the above steps has a structure including not less than 95 % of tempered martensitic structure by area ratio in a cross section of a wire material, a compressive residual stress layer formed from a surface to a depth of 0.35 mm to D/4, in which D (mm) is a circle-equivalent diameter of a cross section, the compressive residual stress layer having maximum compressive residual stress of 800 to 2000 MPa, a center portion with Vickers hardness of 550 to 700 HV in the cross section, and a high hardness layer with greater hardness than the center portion by 50 to 500 HV from a surface to a depth of 0.05 to 0.3 mm. Therefore, the spring in the present invention has a high-strength layer and a high-compressive residual stress layer in a surface layer, and has superior fatigue resistance.

Examples

[0051] Springs were produced according to the steps shown in Fig. 1. That is, an oil tempered wire (SWOSC-V) having a composition shown in Table 1 was prepared and was cold coiled into a predetermined shape by a coiling machine, whereby springs shown in Table 2 were obtained. The springs were subjected to a heat treatment at a condition shown

EP 2 682 493 B2

in Table 3. Next, the springs were subjected to shot peening. In the shot peening, round cut wires with a sphere-equivalent diameter of 0.8 mm were used in a first step. Then, round cut wires with a sphere-equivalent diameter of 0.45 mm were used in a second step. Moreover, the springs were heated to 230 °C for 10 minutes for strain aging and were cooled down to room temperature. Then, the springs were subjected to a setting step according to the invention corresponding to maximum shear strain of 0.020 (maximum shear stress of $\tau = 1565$ MPa, and modulus of rigidity of 78.5 GPa). Various characteristics of the springs were investigated in the following manner with respect to the springs, and results thereof are shown in Table 3. In Table 3, values which do not fulfill the conditions recited by the present invention are underlined.

Table 1

Steel type	Chemical composition (mass%) Balance is iron and inevitable impurities						Ac3 (°C)
	C	Si	Mn	Cr	P	S	
SWOSC-V	0.57	1.42	0.66	0.67	0.01	0.008	806

Table 2

Steel type	SWOSC-V
Wire diameter	4.1 mm
Average coil diameter	24.6 mm
Total coils	5.75
Active coils	3.25
Coiling direction	Right-handed coiling
Free height	42.8 mm
Spring constant	57.3 N/mm

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Table 3

No.	Austenitizing temperature (°C)	Tempering temperature (°C)	Tempering time (minute)	Area ratio of tempered martensite (%)	Maximum compressive residual stress (MPa)	Thickness of compressive residual stress layer (mm)	Hardness at center portion (HV)	Thickness of high hardness layer (mm)	Fatigue resistance	Notes
1	850	<u>500</u>	60	100	<u>610</u>	0.5	<u>407</u>	0.21	Bad	Comparative example
3	850	400	60	99	1119	0.45	673	0.13	Good	Practical example
4	850	350	60	98	1153	0.36	692	0.09	Good	Practical example
5	850	<u>300</u>	60	<u>92</u>	1170	<u>0.3</u>	<u>725</u>	<u>0.04</u>	Bad	Comparative example

Note: The underline indicates that the value does not satisfy the condition described in the present invention.

Claims

1. A production method for a coiled spring, wherein the coiled spring comprises a structure including not less than 95 % of tempered martensitic structure by area ratio in a cross section of a wire material;

a compressive residual stress layer formed from a surface to a depth of 0.35 mm to $D/4$, in which D (mm) is a circle-equivalent diameter of a cross section, the compressive residual stress layer having maximum compressive residual stress of 800 to 2000 MPa;

a center portion with Vickers hardness of 550 to 700 HV in the cross section; and

a high hardness layer with greater hardness than the center portion by 50 to 500 HV from a surface to a depth of 0.05 to 0.3 mm,

wherein the circle-equivalent diameter of the cross section of the wire material is 1.5 to 15 mm and wherein the method comprises:

a step of preparing an oil tempered wire consisting of, by mass %, 0.5 to 0.7 % of C, 1.0 to 2.0 % of Si, 0.1 to 1.0 % of Mn, 0.1 to 1.0 % of Cr, not more than 0.035 % of P, not more than 0.035 % of S, and the balance of Fe and inevitable impurities; and the following steps performed in order;

a step of cold coiling the oil tempered wire into a shape of a spring;

a hardening step for heating the spring up to an austenitizing temperature and cooling down the same to room temperature;

tempering step for heating the spring and cooling the same to room temperature;

a first shot peening step for projecting shots to the spring;

a strain aging step for heating the spring and cooling the same; and

a setting step of providing permanent strain to the spring,

wherein in the hardening step, the austenitizing temperature is A_{c3} point to (A_{c3} point + 250 °C) and is cooled at a cooling rate of not less than 20 °C/second,

in the tempering step, the spring is heated at a temperature of 330 to 480 °C for not less than 20 minutes, in the first shot peening step, the shots has a sphere-equivalent diameter of 0.6 to 1.2 mm, the shots are projected at a speed of 60 to 100 m/s so as to cause coverage of 100 % or more,

in the strain aging step, the spring is heated at a temperature of 150 to 300 °C for 10 minutes or more,

in the setting step, the spring is heated at a temperature of 150 to 300 °C and share strain of 0.015 to 0.022 is generated on a surface of the wire material.

2. The production method for the spring according to claim 1, wherein the method further comprises a second shot peening step for projecting shots to the spring after the setting step, the shots has a sphere-equivalent diameter which is smaller than that of the shots used in the first shot peening step.

Patentansprüche

1. Herstellungsverfahren für eine Spiralfeder, wobei die Spiralfeder aufweist:

eine Struktur, die nicht weniger als 95 % vergütete martensitische Struktur in Flächenanteilen in einer Querschnittsfläche eines Drahtmaterials umfasst;

eine Druckeigenspannungsschicht, die auf einer Oberfläche bis zu einer Tiefe von 0,35 mm bis $D/4$ gebildet ist, wobei D (mm) ein Kreisäquivalent-Durchmesser eines Querschnitts ist, wobei die Druckeigenspannungsschicht eine maximale Druckeigenspannung von 800 bis 2000 MPa aufweist;

einen Zentralabschnitt mit einer Vickers-Härte von 550 bis 700 HV im Querschnitt; und

eine hochharte Schicht mit einer um 50 bis 500 HV von einer Oberfläche bis in eine Tiefe von 0,05 bis 0,3 mm größeren Härte als die des Zentralabschnitts,

wobei der Kreisäquivalent-Durchmesser des Querschnitts des Drahtmaterials 1,5 bis 15 mm ist,

und wobei das Verfahren aufweist:

einen Schritt des Bereitstellens eines ölgehärteten Drahts bestehend aus, nach Gewichts-%, 0,5 bis 0,7 % an C, 1,0 bis 2,0 % an Si, 0,1 bis 1,0 % an Mn, 0,1 bis 1,0 % an Cr, nicht mehr als 0,035 % an P, nicht mehr als 0,035 % an S und den Rest an Fe und unvermeidbaren Verunreinigungen; und die folgenden Schritte, in der Reihenfolge ausgeführt;

EP 2 682 493 B2

einen Schritt des Kaltverformens des ölgehärteten Drahts in die Form einer Feder;
einen Härtungsschritt zum Aufheizen der Feder bis zu einer Austenitisierungstemperatur und Abkühlen derselben auf Raumtemperatur;
einen Vergütungsschritt zum Aufheizen der Feder und Kühlen derselben auf Raumtemperatur;
5 einen ersten Kugelstrahlenschritt zum Bestrahlen der Feder mit Kugeln;
einen Reckalterungsschritt zum Aufheizen der Feder und Kühlen derselben; und
einen Setzschrift zum Vorsehen einer permanenten Dehnung der Feder,
wobei in dem Härtungsschritt die Austenitisierungstemperatur die Ac3-Punkt-Temperatur bis (Ac3-Punkt-Temperatur + 250 °C) ist und gekühlt wird mit einer Kühlrate von nicht weniger als 20 °C/Sekunde,
10 in dem Vergütungsschritt die Feder auf eine Temperatur von 330 bis 480 °C für nicht weniger als 20 Minuten aufgeheizt wird,
in dem ersten Kugelstrahlenschritt, die Kugeln einen kugeläquivalenten Durchmesser von 0,6 bis 1,2 mm haben, wobei die Schüsse mit einer Geschwindigkeit von 60 bis 100 m/s gestrahlt werden, um 100 % oder mehr abzudecken,
15 in dem Reckalterungsschritt, die Feder auf eine Temperatur von 150 bis 300 °C für 10 Minuten oder mehr erhitzt wird,
in dem Setzschrift, die Feder auf eine Temperatur von 150 bis 300 °C aufgeheizt wird und eine Scherspannung von 0,015 bis 0,022 auf einer Oberfläche des Drahtmaterials erzeugt wird.

- 20 2. Herstellungsverfahren nach Anspruch 1, wobei das Verfahren ferner einen zweiten Kugelstrahlenschritt aufweist, zum Strahlen von Kugeln nach dem Setzschrift auf die Feder, wobei die Kugeln einen kugeläquivalenten Durchmesser haben, welcher kleiner ist als der der Kugeln, die in dem ersten Kugelstrahlenschritt genutzt werden.

25 Revendications

1. Procédé de production d'un ressort hélicoïdal, le ressort hélicoïdal comprenant:

30 une structure comprenant pas moins de 95% d'une structure martensitique ayant subi un revenu en rapport de surface en section droite d'une matière en fil;
une couche de contrainte résiduelle à la compression, formée d'une surface jusqu'à une profondeur de 0,35 mm à D/4, D (mm) étant un diamètre équivalent de cercle d'une section transversale, la couche de contrainte résiduelle à la compression ayant une contrainte résiduelle à la compression maximum de 800 à 2 000 mPa;
une partie de centre ayant une dureté Vickers de 550 à 700 HV dans la section transversale et
35 une couche de grande dureté, d'une dureté plus grande de 50 à 500 HV que la partie de centre à partir d'une surface jusqu'à une profondeur de 0,05 à 0,3 mm,
dans lequel le diamètre équivalent à un cercle de la section transversale de la matière en fil va de 1,5 à 15 mm,

et le procédé comprenant:

40 un stade de préparation d'un fil ayant subi un revenu à l'huile et consistant, en % en masse, en 0,5 à 0,7% de C, en 1,0 à 2,0% de Si, en 0,1 à 1,0% de Mn, en 0,1 à 1,0% de Cr, en pas plus de 0,035% de P, en pas plus de 0,035% de S, le solde étant du Fe et des impuretés inévitables; et les stades suivants étant effectués dans l'ordre;
45 un stade d'enroulement à froid du fil ayant subi un revenu à l'huile en la forme d'un ressort;
un stade de trempé pour porter le ressort jusqu'à une température d'austénitisation et le refroidir à la température ambiante;
un stade de revenu pour chauffer le ressort et le refroidir à la température ambiante;
un premier stade de grenailage pour projeter de la grenaille sur le ressort;
50 un stade de vieillissement par écrouissage pour chauffer le ressort et le refroidir et
un stade de stabilisation donnant une contrainte permanente au ressort,
dans lequel, dans le stade de trempé, la température d'austénitisation va du point Ac3 au (point Ac3 + 250°C) et est abaissée à une vitesse de refroidissement qui n'est pas plus petite que 20°C/seconde,
dans le stade de recuit, le ressort est porté à une température de 330 à 480°C pendant pas moins de 20 minutes,
55 dans le premier stade de grenailage, la grenaille a un diamètre équivalent à une sphère de 0,6 à 1,2 mm, la grenaille étant projetée à une vitesse de 60 à 100 m/s, de manière à donner un recouvrement supérieur ou égal à 100%,
dans le stade de vieillissement par écrouissage, le ressort est porté à une température de 150 à 300°C pendant

EP 2 682 493 B2

10 minutes ou plus,
dans le stade de stabilisation, le ressort est porté à une température de 150 à 300°C et une contrainte de
partage de 0,015 à 0,022 est produite sur une surface de la matière en fil.

- 5 **2.** Procédé de production du ressort suivant la revendication 1, dans lequel le procédé comprend, en outre, un deuxième
stade de grenailage pour projeter de la grenaille sur le ressort après le stade de stabilisation, la grenaille ayant un
diamètre équivalent de sphère qui est plus petit que celui de la grenaille utilisée dans le premier stade de grenailage.

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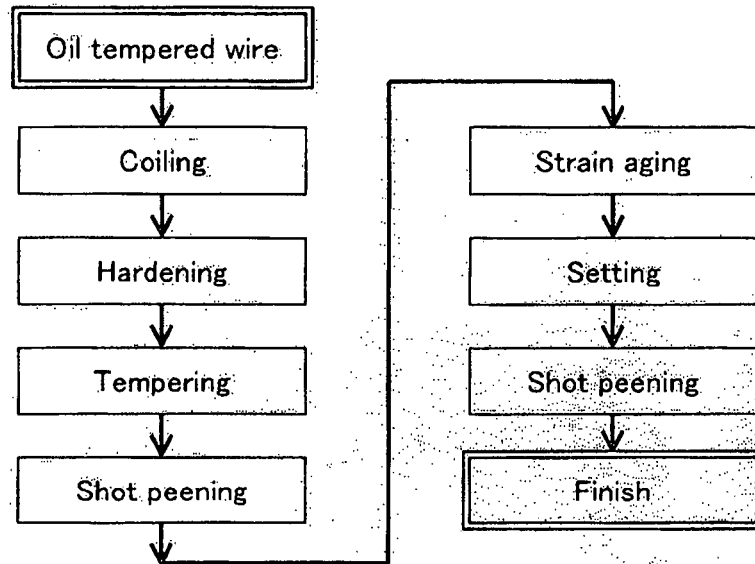
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Fig. 1



REFERENCES CITED IN THE DESCRIPTION

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